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A Dosimetric Comparison of Jaw Tracking versus Non-Jaw Tracking Using 6MV VMAT Treatment Beams in Prostate Patients with Involved Lymph Nodes

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Abstract

Introduction:

Jaw tracking is the process of the collimator jaws dynamically following the multileaf collimators during modulated therapy. Jaw tracking can be used throughout the dosimetry treatment planning process for IMRT and VMAT treatment plans. It can reduce a patient's OAR dose by reducing low dose spillage from MLC interleaf leakage. This study aims to investigate if jaw tracking reduces OAR dose while maintaining PTV coverage in prostate patients with involved lymph nodes using 6MV VMAT treatment planning technique.

Methods:

This is a quantitative study of 10 patients. For each patient, two plans were created, one plan using a non-jaw tracking technique, and the other plan incorporating a jaw tracking technique. Volumetric OAR doses, overall PTV coverage, Gradient Index, Conformity Index, and Homogeneity Index were recorded for both plans, and a dosimetric comparison was performed. Results were evaluated using the Wilcoxon signed-rank test.

Results:

Results of this study indicated statistically lower OAR dose on the JT plans than on non-JT plans. The bladder constraint doses were lower on the JT plans. The rectum constraint doses for the JT plans were statistically lower than the non-JT plans. The right and left femoral heads doses were lower on the JT plans than the non-JT plans. The max dose for the bowel bag and sigmoid colon were statistically lower for the JT plans. While the PTV 7020 and PTV 4680 coverage was lower for the JT plans compared to the non-JT plans.

Conclusion:

A dosimetric reduction was found for most OAR dose constraints for the JT technique, providing better OAR sparing to help reduce organ toxicities. Using this technique, however, resulted in reduced coverage to the PTV 4680 and PTV 7020 volumes.

Introduction

Prostate cancer is a prominent cancer diagnosis among men in the United States, accounting for approximately 268,490 new cases annually[1]. On average, about 1 in 8 men are diagnosed with prostate cancer during their lifetime, with 60% of the diagnoses occurring in men 65 years and older. The mortality rate of prostate cancer among American men is about 1 in 41, resulting in it being the second most common cause of cancer related death, following lung cancer.[1] Prostate cancer screening is used to detect cancer at an early stage before symptoms are present, with the intention of providing a more successful treatment outcome paired with an improved prognosis. The screening involves a blood test to detect the prostate specific antigen (PSA) level, and a digital rectal exam (DRE).[2] As PSA levels rise, the chance of developing prostate cancer increases. Since there is no specific PSA level that definitively determines a man has prostate cancer, levels between 4-10ng/mL are considered borderline and indicates that a man has about a 25% chance of having prostate cancer. As PSA levels increase to above 10ng/mL the chance of having prostate cancer increases to over 50%. Because of this, most physicians recommend further testing for PSA levels above 4ng/mL.[1] If results from a PSA test or DRE indicate suspicion of cancer, the only way to definitively diagnose it is through a prostate biopsy. The tissue sample from the biopsy is evaluated under a microscope to determine if the cells are representative of cancer. Given its nature for developing in gland cells, adenocarcinoma is the most common histology for prostate cancer.[1]

After a prostate cancer diagnosis, the cancer is assigned a clinical stage and grade. A cancer grade is used to determine cancer abnormality. The Gleason score defines tumor grade based on how similar or different the cancer cells appear compared to normal prostate tissue.[3] The higher the tumor grade, the more poorly differentiated the cancer cells are from healthy

prostate tissue. This indicates the cancer cells to be more aggressive, and a greater likelihood the cancer will spread outside the prostate. In addition to the cancer grade, the American Joint Committee on Cancer (AJCC) Tumor/Node/Metastasis (TNM) system is used to assign the patient a cancer stage to classify the extent of cancer spread.[1]

Treatment options are determined based on the cancer histology, Gleason score, and TNM staging. Radiation therapy can be used as the first line of treatment for low grade prostate tumors that are still contained within the prostate gland. For cancers that have spread to nearby tissue outside of the prostate, radiation therapy can also be used as a first treatment option when paired with hormone therapy.[1] If the tumor is not completely removed during a prostatectomy, or if the cancer recurs in the prostate area, salvage radiation therapy can be used as a treatment option.[4]

The prostate gland is located anterior to the rectum, posterior to the bladder, inferior to bowel and medial to the femoral heads.[5] These organs are considered the Organs at Risk (OAR's) and should be given special considerations to limit their dose when planning a prostate treatment. With the maximum dose these OAR's can receive being lower than the total prescription dose for a prostate, effective OAR sparing can decrease acute and late toxicities to these organs. Therefore, during the treatment planning process, dose constraints are assigned by the radiation oncologist to be followed for each OAR to preserve the function of the critical structures during and after a patient's radiation treatment.[6]

Multileaf collimators (MLCs) located in the gantry are used to conform dose around a target volume and to spare OARs. During a prostate radiation therapy treatment, MLCs move to conform to the prostate region to treat only the desired area and block out the critical nearby

structures that do not need radiation dose from the treatments. When radiation exits the gantry and penetrates the MLCs, the MLCs absorb the radiation and prevent that dose from reaching the patient. MLCs range in size with the typical widths between 0.25cm, 0.5cm, and 1.0cm. Neighboring MLC leaves have small gaps between them, allowing interleaf leakage to be transmitted to the patient. This leakage accounts for up to 2% increase in the amount of low dose radiation to blocked OARs in the patient.[7]

A technique of jaw tracking has been developed to reduce the amount of interleaf leakage during Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) treatments. As the machines MLCs move, the secondary jaws follow the MLCs to absorb the leakage and better reduce unnecessary dose to the patient.[8] The purpose of this study is to conduct a dosimetric comparison of jaw tracking vs. fixed jaw in VMAT prostate patients with lymph node involvement using a 6MV flattening filter beam arrangement. The researcher hypothesizes the use of jaw tracking on VMAT prostate plans will provide decreased dose to OARS and better coverage to the PTV.

Previous research on jaw tracking vs. non-jaw tracking has been performed on VMAT studies to see if there is a reduction in dose to the patients where jaw tracking is used during radiation treatments. A study conducted in 2018, “Dosimetric Effect of Jaw Tracking in Volumetric Modulated Arc Therapy” aimed to research the effects of using jaw tracking on VMAT plans. The study was performed on multiple sites of the body including nasopharyngeal cancers, lung cancers, and prostate cancers.[9] Another study performed in 2021, “Dosimetric Evaluation of Fixed Jaw and Jaw Tracking VMAT Treatment Plans for Prostate Cancer with Involved Pelvic Nodes” compared VMAT treatment plans on 16 prostate patients with lymph nodes treated. The two plans were created using 10MV and flattening filter free beams.[10]

Materials and Methods

Patient Selection

This retrospective study was conducted upon submission and approval to the hospital institutional review board (IRB) and Grand Valley State University IRB. Ten patients who had previously completed prostate with lymph node treatments were then retrospectively selected. Exclusion criteria for the selection process included subjects younger than 25 years of age at the time of CT simulation and any patient who opted out of participating in research studies at time of consenting for radiation therapy. Upon subject selection, it was verified that each patient was diagnosed with an ICD 10 code of C61, indicating malignant neoplasm of the prostate. All patients received care from the same radiation oncologist between May 2021 and August 2022. The mean age of patients was 70 years. The average Gleason score for the subjects in this study was eight, and the stage ranged from T1c N0 M0 to T3b N1 M0. Diagnosis characteristics and age are shown on Table 1.

Planning Techniques

Patients were simulated on a Philips Big Bore CT scanner using 3mm slice thickness. They were positioned in a head-first supine position, with their arms placed high on their chest and a custom Vac Bag made for immobilization under the patient's legs. For consistency, OAR contours were all contoured following the Radiation Therapy Oncology Group male pelvis normal tissue guidelines.[11] The planning target volumes were drawn by the same radiation oncologist overseeing the patient's care. Critical structures that were evaluated in this study were the bladder, rectum, bowel, and right femoral head and left femoral head. The mean size of the

critical structure volumes was 371.72 cm^3, 79.44 cm^3, 1904.99 cm^3, 160.79 cm^3, and 160.13 cm^3 respectively.

A dose painting technique was used, to plan the primary target volume and boost volume to be treated simultaneously to a different prescribed total dose. The primary target volume encompasses the prostate, seminal vesicles, and the pelvic lymph node chains. This was planned to a dose of 4680cGy, given at 180cGy a day for 26 fractions. The prostate boost target volume encompasses the prostate and was planned to a total dose of 7020cGy at a daily fraction dose of 270cGy for 26 fractions. The average volume size for the primary PTV4680 was 621.43cm^3, and the average volume size for the boost PTV 7020 was 107.31cm^3.

Treatment planning was completed on Pinnacle treatment planning system version 16.2. All patients were planned using 6MV flattening filter beams for a Varian TrueBeam Linear Accelerator. A VMAT technique with two full arcs was used. A collimator rotation of 30 degrees was applied for the first arc and 330 degrees for the second. Planning PTV coverage objectives included 95% of the target volume receives 100% of the prescribed dose, and a max dose less than 110% of the prescription dose. For each patient, both a non-jaw tracking plan and jaw tracking plan were created and optimized one time independently of each other towards meeting the planning PTV objectives and the OAR dose constraints. These constraints include $V_{70.2}$ < 10%, V_{50} < 15%, V_{40} < 25%, V_{35} < 35%, V_{20} < 50% for the bladder, $V_{70.2}$ < 10%, V_{40} < 15%, V_{35} < 25%, V_{25} < 35%, V_{20} < 50% for the rectum, V_{25} < 10%, V_{15} < 25% for the femoral heads, max dose of 54Gy for the sigmoid colon, and max dose of 50Gy for the bowel bag. OAR planning objectives are shown in Table 2.

Plan Evaluation

The primary and boost target volume coverage was assessed, along with the dose to their respective OARs. To evaluate both PTV volumes for coverage and conformality, the $V_{95\%}$, $V_{100\%}$, conformity index, and gradient index were assessed. The conformity index is used to assess the correlation between reference isodose distributions and the target volume.[12] RTOG describes the conformity index with the equation CI = Volume of Reference Isodose / Target volume.[13] For this study, the 100% isodose volume was used to review the conformity index. To evaluate the gradient index the equation GI= Volume of 50% prescription dose / Volume of 100% prescription dose was used. The GI is useful in assessing treatment plans for dose fall off outside the target volume.[14]

To evaluate dose to the OAR's, each critical structure had its own volumetric constraints that were analyzed. These included the $V_{70.2}$, V_{50}, V_{35}, V_{20} for the bladder, $V_{70.2}$, V_{40}, V_{35}, V_{25} for the rectum, V_{25}, V_{15} for the femoral heads, and D_{max} for the small bowel and sigmoid colon. These constraints were evaluated on both the jaw tracking and non-jaw tracking plans, and a dosimetric comparison was performed to compare the results.

Results

The goal of this study was to evaluate the effectiveness of jaw tracking in prostate patients with involved lymph nodes using 6MV photon beams. The objective being, to see if it was superior at sparing OARs while maintaining adequate PTV coverage compared to a non-jaw tracking technique. Ten previously treated prostate cancer patients with involved lymph nodes were randomly selected for this study. A Wilcoxon signed-rank test was used to compare the two techniques, and a p-value of < 0.05 was considered statistically significant. All results are displayed in Table 3. Overall, the gradient index for the JT technique ($M = 26.44$, $SD = 8.00$) for

PTV 7020 was not statistically significant in comparison to the non-JT technique (M = 23.60, SD = 8.86), p = 0.1309. In contrast, the gradient index for the JT technique (M = 7.68, SD = 1.85) for PTV4680 had statistically significant dose fall off compared to the non-JT technique (M = 5.27, SD = 0.68), p = 0.0020. Additionally, the conformity index between the two techniques proved to have statistically significant conformality for the non-JT plans (M = 0.86, SD = 0.07) compared to the JT plans (M = 0.69, SD = 0.11), p = 0.0098.

The PTV 4680 target volume coverage was assessed through evaluating the 95% and 100% isodose lines. The JT PTV 4680 100% coverage ranged from 15.01% to 48.71% and had a median coverage of 39.62%. The non-JT coverage ranged from 71.32% to 97.50% with a median coverage of 79.86%. The non-JT technique (M=81.76, SD = 8.25) reported statistically significantly higher PTV 4680 coverage of the 100% isodose line compared to the JT technique (M = 36.77, SD = 10.61), p = 0.0020. When evaluating the 95% isodose line for the JT PTV4680 plans the coverage ranged from 82.44% to 97.44% and had a median of 95.07% coverage at 4446cGy. The non-JT plans coverage ranged from 98.90% to 99.98%, with a median of 99.6% at 4446cGy. The non-JT technique (M = 99.51, SD = 0.38) reported significantly higher PTV 4680 coverage of the 95% isodose line compared to the JT technique (M = 93.16, SD = 5.05), p = 0.002. PTV 4680 coverage findings are displayed in Table 4.

The PTV 7020 target volume coverage was assessed through evaluating the 95% and 100% isodose lines. The JT PTV 7020 100% coverage ranged from 53.46% to 84.43% and a median coverage of 73.96% at 7020cGy. The non-JT coverage ranged from 76.13% to 95.85% with a median coverage of 87.95% at 7020cGy. The non-JT technique (M=85.89, SD = 6.11) reported a statistically significant higher PTV 7020 coverage of the 100% isodose line compared to the JT technique (M = 72.27, SD = 10.04), p = 0.0137. When evaluating the 95% isodose line

for the JT PTV 7020 plans the coverage ranged from 88.18% to 99.87% and had a median of 99.16% coverage at 6669cGy. The non-JT plans coverage ranged from 99.03% to 99.99%, with a median of 99.69% at 6669cGy. The non-JT technique (M = 99.60, SD = 0.37) reported a statistically significant higher PTV7020 coverage of the 95% isodose line compared to the JT technique (M = 98.12, SD = 53.53), p = 0.0059. PTV 7020 coverage findings are displayed in Table 5.

There were five planning constraints used to evaluate the bladder dose on all plans. The first constraint $V_{70.2} < 10\%$ had a range of 0.70% to 4.02% for the JT technique, with a median of 1.91%, compared to a range of 0.81% to 5.08% for the non-JT technique, with a median of 2.81%. This was a statistically significant lower dose to the bladder $V_{70.2}$ for the JT plans (M = 2.18, SD = 1.11) as to the non-JT plans (M = 2.68%, SD = 1.34), p = 0.0059. The following constraint, $V_{50} < 15\%$, was evaluated. This constraint ranged from 5.27% to 17.06%, with a median of 11.34% for the JT plans, and ranged from 6.13% to 17.61%, having a median of 11.87% for the non-JT plans. The Wilcoxon signed-rank test determined the JT technique had a statistically significant lower V_{50} dose for the JT technique (M = 11.22%, SD = 3.42) compared to the non-JT technique (M = 11.73%, SD = 3.32), p = 0.0273. When evaluating the V_{40} constraint, $V_{40} < 25\%$ was assessed. This ranged from 12.92% to 27.56%, with a median of 24.07% for the JT plans, and ranged from 15.94% to 28.15%, with a median of 25.25% for the non-JT plans. There was statistically significant evidence the JT plans (M = 22.89%, SD = 4.32) spared the bladder V_{40} better than the non-JT plans (M = 24.32%, SD = 3.82), p = 0.002. The next constraint assessed for the bladder was the $V_{35} < 35\%$. For this constraint, the JT technique ranged from 17.09% to 33.75%, having a median of 29.88%. The non-JT technique had a range of 21.04% to 34.73%, with a median of 31.10%. The JT plans (M = 28.86%, SD = 5.01) reported

statistically significant lower V_{35} dose compared to non-JT plans (M = 30.17%, SD = 4.29), p = 0.0039. The final constraint evaluated for the bladder was the $V_{20} < 50\%$. For this constraint, the range for the JT plans was 38.84% to 59.30%, and a median of 49.63%. The non-JT plans ranged from 45.02% to 74.54%, with a median of 52.64%. After performing the Wilcoxon signed-rank test there was significant evidence that the JT technique (M = 50.00%, SD = 6.40) had lower V_{20} doses compared to the non-JT technique (M = 54.07, SD = 8.55), p = 0.002.

For evaluation for the rectum, five planning constraints were assessed on all plans. The first constraint $V_{70.2} < 10\%$ had a range of 0.00% to 1.69% for the JT technique, with a median of 0.73%, compared to a range of 0.00% to 3.04% for the non-JT technique, median 1.23%. This was a statistically significant lower dose to the rectum $V_{70.2}$ for the JT plans (M = 0.69%, SD = 0.52) as to the non-JT plans (M = 1.22%, SD = 0.91), p = 0.0039. The $V_{40} < 15\%$ constraint was evaluated. This constraint had a range of 6.75% to 15.84%, with a median of 14.90% for the JT plans, and ranged from 7.55% to 16.86%, having a median of 15.18% for the non-JT plans. The Wilcoxon signed-rank test determined the JT technique had a statistically significant lower V_{40} dose for the JT technique (M = 13.36%, SD = 3.03) compared to the non-JT technique (M = 14.23%, SD = 2.81), p = 0.0371. When evaluating the V_{35} constraint, $V_{35} < 25\%$ was assessed. This ranged from 15.49% to 20.70%, with a median of 19.03% for the JT plans, and ranged from 16.27% to 22.31%, with a median of 19.56% for the non-JT plans. There was significant evidence the JT plans (M = 18.54%, SD = 1.73) spared the rectum V_{35} better than the non-JT plans (M = 19.52%, SD = 1.85), p = 0.0645. The next constraint assessed for the rectum was the $V_{25} < 35\%$. For this constraint, the JT technique ranged from 25.64% to 37.55%, having a median of 31.82%. The non-JT technique had a range of 26.64% to 38.90%, with a median of 32.90%. The JT plans (M = 31.15%, SD = 3.71) reported a statistically significant lower V_{25}

dose compared to non-JT plans (M = 32.64%, SD = 3.71), p = 0.0273. The final constraint evaluated for the rectum was the V_{20} < 50%. For this constraint, the range for the JT plans included 33.51% to 50.86% and a median of 45.02%, while the non-JT plans ranged from 41.39% to 54.20%, with a median of 46.90%. After performing the Wilcoxon signed-rank test there was significant evidence that the JT technique (M = 43.96%, SD = 4.74) had lower V_{20} doses compared to the non-JT technique (M = 47.46, SD = 3.71), p = 0.002.

The planning objectives for the right femoral head that were evaluated included V_{25} < 10% and V_{15} < 25%. When assessing the V_{25} for the JT plans the volume ranged from 0.19% to 3.63% and had a median of 1.04%. The non-JT plans had a range of 0.84% to 5.27%. The Wilcoxon signed-rank test indicated there was no significant evidence of a difference for the right femoral head V_{25} in JT plans (M = 1.21, SD = 1.07) vs. non-JT plans (M = 2.41, SD = 1.53), p = 0.084. The right femoral head V_{15} was also evaluated with a range for the JT plans of 4.22% to 18.85%, with a median dose of 6.49%. The non-JT plans ranged from 9.34% to 29.71%, having a median dose of 19.21%. The JT plans (M = 8.23, SD = 4.38) reported statistically significant lower doses to the right femoral head compared to the non-JT plans (M= 18.66, SD = 6.74), p = 0.0098.

Two planning objectives for the left femoral head were evaluated; V_{25} < 10% and V_{15} < 25%. The volume of dose to V_{25} for the JT plans ranged from 0.00% to 1.39% and had a median of 0.67%. The non-JT plans had a range of 0.21% to 5.08% with a median of 2.88%. After performing the Wilcoxon signed-rank test, the results indicated statistical significance that the JT plans (M = 0.65, SD = 0.53) have lower V_{25} dose than non-JT plans (M = 2.98, SD = 1.34), p = 0.002. The left femoral head V_{15} was also evaluated with a range for the JT plans of 4.33% to 14.55%, and a median dose of 8.27%. The non-JT plans ranged from 10.54% to 28.93%, having

a median dose of 23.10%. The JT plans (M = 8.23, SD = 4.38) reported statistically significant lower doses to the left femoral head compared to the non-JT plans (M= 21.42, SD = 6.28), p = 0.002.

To evaluate the bowel bag between the two techniques, the max doses were compared. The constraint used for planning was that the bowel bag received less than 50Gy. The max dose range for the JT plans was 4665.6cGy to 5542.2cGy, with a median of 4888.05cGy. The non-JT plans ranged from 4779.3cGy to 5587.9cGy, with a median of 4959.25cGy. The JT technique (M = 4906.60, SD = 248.20) reported statistically significant lower doses to the bowel bag compared to the non-JT technique (M499.49, SD = 230.17), p=0.002.

To assess the sigmoid colon, the max doses between JT and non-JT were compared. The planning constraint used for this structure was a max dose of less than 54Gy. The JT plans ranged from 4497.8cGy to 5398.8cGy with a median of 4845.7cGy, while the non-JT plans ranged from 4787.3cGy to 5486.1cGy and a median of 5017.75cGy. The JT technique (M = 4886.15, SD = 229.95) showed statistical significance in lower sigmoid doses compared to the non-JT technique (M = 5037.53, SD = 217.54), p = 0.0215.

Discussion

The purpose of this study was to evaluate OAR dose and PTV coverage with the implementation of jaw tracking in VMAT treatment plans for prostate with involved lymph node patients. This was conducted through creating and comparing ten non-jaw tracking plans to ten jaw tracking plans for the same ten patients. Each plan was run through the optimizer one time with the same planning objectives entered. As stated in the results section, the dose to the

treatment OARs was significantly decreased with the jaw tracking plans. Consequently, the PTV coverage was also decreased for each jaw tracking plan.

The treatment planning system used was Pinnacle 16.2. A limitation encountered during this study was the inability to optimize the jaw tracking plan to its full extent, then copy the plan and apply the non-jaw tracking technique. With this version of Pinnacle, a plan needs to be reoptimized to incorporate jaw tracking on non-jaw tracking plans, and reoptimized to implement non-jaw tracking on prior optimized jaw tracking plans. As a result of the optimization limitation, a non-jaw tracking plan and jaw tracking plan were run in the optimizer independently of each other. The same OAR optimization goals, target optimization goals, and auto-planning settings were entered for each plan, with the only difference being the first plan not utilizing jaw tracking, and the second plan adding in jaw tracking.

When evaluating the PTV 4680 and PTV 7020 the most surprising result of the study was the lower target volume coverage for the jaw tracking plans. When reviewing the plans, this was understandable; the jaw tracking technique lowered the dose to all structures, PTV and OARs included. After reviewing the statistical analysis, the jaw tracking plans were optimized further and gained comparable coverage to the non-jaw tracking plans while maintaining similar OAR doses. The primary investigator believes an area for further research could include running plans to full optimization. and comparing critical organ dose and PTV coverage. This methodology was not feasible for this investigation as the two techniques would not be a true comparison due to each JT and non-JT plan requiring independent optimization.

When evaluating the bladder dose, the results were expected as the jaw tracking plans showed lower dose to the bladder for all five constraints evaluated. The difference in the average

percent dose for the $V_{70.2}$ constraint was 0.5% lower for the jaw tracking plans to the non-jaw tracking plans. When evaluating the V_{50} coverage, the jaw tracking plan had a 0.51% lower dose to the bladder compared to the non-jaw tracking plans. Furthermore, the V_{40} and V_{35} had a difference in overall percent dose of 1.43% & 1.31% respectively from the jaw tracking technique to the non-jaw tracking technique. The V_{20} reported a difference of 4.07%b between the jaw tracking technique and the non-jaw tracking technique. These results were all determined significant from the Wilcoxon signed-rank test as expected. The bladder findings are displayed in Table 6.

An evaluation of the rectum dose included a review of five planning constraints. The difference in the average percent dose for the $V_{70.2}$ constraint was 0.53% lower for the jaw tracking plans compared to the non-jaw tracking plans. When evaluating the V_{40} coverage, the jaw tracking plan had a 0.87% lower dose to the rectum compared to the non-jaw tracking plans. Additionally, the V_{35} and V_{25} had a difference in overall percent dose of 0.98% and 1.49% respectively, from the jaw tracking technique to the non-jaw tracking technique. Lastly, the V_{20} reported a difference of 3.5% between the jaw tracking technique and the non-jaw tracking technique. All results proved to be significant from the Wilcoxon signed-rank test, which was expected. These findings are shown in Table 7.

The right and left femoral heads followed two constraints. The left V_{25} had a difference in overall percent dose of 2.33%, while the left V_{15} had a 13.38% difference in overall percent dose to the constraint objective. Both results were the anticipated outcomes. In contrast, the right femoral head V_{25} had an overall percent dose range of 1.21%, which did not indicate a statistically significant lower dose for the JT plan. This was unexpected, as the opposing femoral head did indicate significance. However, the V_{15} did report, as expected, significantly lower dose

for that constraint with the JT plan. The difference in overall average percent dose was 10.43%. Results to the right and left femoral heads are displayed in Table 8.

The bowel bag and sigmoid colon are both important structures to evaluate. A dosimetric evaluation of the bowel bag showed an advantage for using a jaw tracking technique to lower the max dose compared to a non-jaw tracking technique. The overall average difference in max dose for the JT plans compared to non-JT plans was 90.89cGy lower dose to the JT plans. Additionally, the sigmoid colon also concluded there is statistically significant lower dose to the sigmoid colon using the JT technique with an overall difference in average max doses 151.38cGy lower to the JT plans. These were the anticipated results for this study and are shown in Table 9.

Conclusion

For men who are treated with radiation therapy to the prostate and involved lymph nodes it is important to adequately spare nearby OARs while maximizing dose to the target volumes to provide an optimal treatment. Effective OAR sparing can help reduce early and late toxicities to the critical organs.[6] Jaw tracking is a technique that has been implemented to help reduce low dose leakage to these critical structures. To evaluate its effectiveness, this study analyzed several components including PTV 7020, PTV 4680, gradient index, homogeneity index, and OAR dose including bladder, rectum, left femoral head, right femoral head, sigmoid colon, and bowel bag. Although results overall showed the jaw tracking technique to have a reduction in OAR dose, there was also a significant amount of reduction in PTV 7020 and PTV 4680 coverage. For further research, optimizing the two techniques to their fullest potential or incorporating a mixed energy technique is recommended to continue evaluation of jaw tracking effectiveness.

Table 1. Patient demographics.

Patient	Gleason Score	TNM Stage	Age
1	4 + 4 = 8	T3b, N0, M0	64
2	4 + 5 = 9	T3b, N0, M0	73
3	4 + 5 = 9	T3b, N0, M0	73
4	4 + 5 = 9	T2, N1, M0	61
5	4 + 3 = 7	T3b, N0, M0	71
6	4 + 4 = 8	T1c, N0, M0	78
7	4 + 4 = 8	T3b, N0, M0	81
8	4 + 4 = 8	T1c, N0, M0	76
9	4 + 3 = 7	T2c, N0, M0	62
10	4 + 5 = 9	T2b, N0, M0	60

Table 2. OAR Planning Objectives.

Organ	$V_{10\%}$	$V_{15\%}$	$V_{25\%}$	$V_{35\%}$	$V_{50\%}$	Max Dose
Bladder	70.2Gy	50Gy	40Gy	35Gy	20Gy	
Rectum	70.2Gy	40Gy	35Gy	25Gy	20Gy	
Femoral heads	25Gy		15Gy			
Sigmoid						5400
Bowel Bag						5000

Table 3. Results of a dosimetric comparison between JT technique and non-JT technique.

Parameters	JT Technique	Non-JT Technique	p-value
PTV 7020			
V_{100} (%)	72.27 ± 10.04	85.89 ± 6.11	0.0137
V_{95} (%)	98.12 ± 3.53	99.60 ± 0.37	0.0059
PTV 4680			
V_{100} (%)	36.77 ± 10.61	81.76 ± 8.25	0.0020
V_{95} (%)	93.16 ± 5.05	99.51 ± 0.38	0.0020
Bladder			
$V_{70.2}$ (%)	2.18 ± 1.11	2.68 ± 1.34	0.0059
V_{50} (%)	11.22 ± 3.42	11.73 ± 3.32	0.0273
V_{40} (%)	22.89 ± 4.32	24.32 ± 3.82	0.0020
V_{35} (%)	28.86 ± 5.01	30.17 ± 4.29	0.0039
V_{20} (%)	50.00 ± 6.40	54.07 ± 8.55	0.0020
Rectum			
$V_{70.2}$ (%)	0.69 ± 0.52	1.22 ± 0.91	0.0039
V_{40} (%)	13.36 ± 3.03	14.23 ± 2.81	0.0371
V_{35} (%)	18.54 ± 1.73	19.52 ± 1.85	0.0645
V_{25} (%)	31.15 ± 3.71	32.64 ± 3.71	0.0273
V_{20} (%)	43.96 ± 4.74	47.46 ± 3.71	0.0020
Right Femoral Head			
V_{25} (%)	1.21 ± 1.07	2.41 ± 1.53	0.0840
V_{15} (%)	8.23 ± 4.38	18.66 ± 6.74	0.0098
Left Femoral Head			
V_{25} (%)	0.65 ± 0.53	2.98 ± 1.34	0.0020
V_{15} (%)	8.04 ± 3.00	21.42 ± 6.28	00.020
Bowel Bag			
$D_{max} < 50$	4906.60 ± 248.20	4997.49 ± 230.17	0.0020
Sigmoid Colon			
$D_{max} < 54$	4886.15 ± 229.95	5037.53 ± 217.54	0.0039

Table 4. PTV 4680 Coverage.

PTV 4680 Coverage				
Patient	95% Coverage - 4446cGy Non-JT	95% Coverage - 4446cGy JT	100% Coverage- 4680cGy Non-JT	100% Coverage- 4680cGy JT
1	99.93%	97.08%	87.41%	33.00%
2	99.98%	96.84%	90.69%	43.79%
3	98.90%	92.90%	78.33%%	41.16%
4	99.17	94.07%	76.72%	38.07%
5	99.78%	97.44%	79.37%	46.61%
6	99.74%	91.33%	80.35%	23.45%
7	99.21%	96.06%	71.32%	42.76%
8	99.12%	82.44%	97.50%	48.71%
9	99.26%	96.75%	72.02%	35.12%
10	99.97%	86.68%	83.91%	15.01%

Table 5. PTV 7020 Coverage.

PTV 7020 Coverage				
Patient	95% Coverage - 6669cGy Non-JT	95% Coverage - 6669cGy JT	100% Coverage- 7020cGy Non-JT	100% Coverage- 7020cGy JT
1	99.99%	99.87%	90.50%	63.52%
2	99.89%	98.79%	89.79%	53.46%
3	99.03%	98.30%	77.73%	64.08%
4	99.39%	99.29%	81.99%	71.71%
5	99.79%	99.59%	82.87%	84.43%
6	99.96%	99.76%	87.74%	76.28%
7	99.14%	88.18%	88.18%	76.20%
8	99.58%	99.69%	76.13%	84.31%
9	99.26%	98.66%	88.15%	80.51%
10	99.97%	99.03%	95.85%	68.19%`

Table 6. Bladder dose constraints results.

Bladder										
Patient	Goal $V_{7020} < 10\%$		Goal $V_{5000} < 15\%$		Goal $V_{4000} < 25\%$		Goal $V_{3500} < 35\%$		Goal $V_{2000} < 50\%$	
	Non-JT	JT	Non-JT	JT	Non-JT	JT	Non-JT	JT	Non-JT	JT
1	1.22%	0.94%	6.13%	5.27%	15.94%	12.92%	21.04%	17.09%	45.50%	38.84%
2	2.96%	1.88%	10.26%	9.84%	21.71%	20.37%	26.85%	25.84%	52.86%	45.73%
3	2.12%	1.94%	11.56%	11.92%	25.10%	24.41%	30.76%	29.70%	50.78%	49.54%
4	2.77%	2.52%	13.40%	13.44%	28.15%	26.50%	34.73%	33.55%	60.90%	59.30%
5	0.81%	0.70%	7.55%	6.75%	20.95%	19.73%	26.64%	25.64%	45.02%	43.90%
6	3.37%	2.87%	12.17%	11.34%	24.20%	23.73%	29.71%	29.30%	49.75%	48.91%
7	5.08%	4.02%	17.61%	17.06%	27.91%	27.56%	33.48%	33.75%	55.60%	54.13%
8	1.44%	1.60%	11.03%	11.19%	27.03%	25.86%	34.57%	32.84%	74.54%	59.12%
9	4.22%	3.80%	14.79%	14.07%	26.79%	25.26%	32.45%	30.79%	52.41%	49.71%
10	2.84%	1.57%	12.75%	11.33%	25.39%	22.55%	31.44%	30.05%	53.34%	50.78%

Table 7. Rectum dose constraints results.

Rectum										
Patient	Goal $V_{7020} < 10\%$		Goal $V_{4000} < 15\%$		Goal $V_{3500} < 25\%$		Goal $V_{2500} < 35\%$		Goal $V_{2000} < 50\%$	
	Non-JT	JT	Non-JT	JT	Non-JT	JT	Non-JT	JT	Non-JT	JT
1	1.19%	0.58%	14.80%	14.58%	19.02%	18.32%	32.89%	31.01%	47.03%	41.39%
2	0%	0%	15.73%	11.34%	20.41%	15.49%	31.87%	25.77%	41.39%	33.51%
3	1.50%	1.20%	16.86%	15.63%	22.31%	20.70%	38.90%	37.55%	54.20%	50.86%
4	3.04%	1.69%	15.66%	15.40%	19.59%	19.40%	34.79%	33.43%	49.30%	46.52%
5	0.81%	0.70%	7.55%	6.75%	20.95%	19.73%	26.64%	25.64%	45.02%	43.90%
6	0.22%	0.03%	11.22%	10.16%	16.27%	15.67%	32.90%	32.74%	46.77%	46.21%
7	1.72%	0.87%	15.56%	15.37%	19.52%	19.34%	30.64%	29.94%	44.70%	40.41%
8	0.46%	0.22%	14.61%	13.30%	19.34%	18.15%	34.72%	32.63%	51.19%	46.13%
9	1.27%	0.76%	16.24%	15.84%	20.97%	19.88%	35.53%	33.87%	49.71%	47.08%
10	1.94%	0.86%	14.08%	15.22%	16.83%	18.71%	27.47%	28.91%	45.28%	43.57%

Table 8. Femoral Heads dose constraints results.

	Right Femoral Head				**Left Femoral Head**			
Patient	Goal $V_{2500} < 10\%$		Goal $V_{1500} < 25\%$		Goal $V_{2500} < 10\%$		Goal $V_{1500} < 25\%$	
	Non- JT	JT	Non-JT	JT	Non-JT	JT	Non-JT	JT
1	4.19%	3.63%	27.84%	10.22%	2.34%	1.39%	25.58%	9.11 %
2	1.13%	2.06%	11.21%	10.04%	0.21%	0%	10.86%	6.12%
3	0.84%	1.71%	9.34%	18.85%	4.25%	0.87%	23.64%	14.55%
4	3.65%	1.38%	18.65%	6.02%	2.55%	0.42%	28.93%	8.12%
5	2.49%	0.45%	11.92%	5.11%	3.21%	0.0%	10.54%	4.33%
6	5.27%	0.19%	20.23%	4.71%	2.37%	1.33%	26.23%	8.45%
7	1.04%	0.22%	16.66%	6.39%	4.05%	0.79%	25.59%	10.42%
8	0.98%	1.16%	21.31%	6.59%	2.53%	0.05%	20.98%	6.09%
9	2.02%	0.92%	29.71%	10.12%	3.23%	1.10%	19.24%	8.41%
10	2.46%	0.35%	19.77%	4.22%	5.08%	0.54%	22.56%	4.82%

Table 9. Sigmoid & Bowel Bag max dose results.

	Sigmoid Goal $D_{max} < 54$		**Bowel Bag Goal $D_{max} < 50$**	
Patient	Non-JT	JT	Non-JT	JT
1	4787.3	4743.5	4823.9	4749.9
2	5486.1	5398.8	5587.9	5542.2
3	5043.8	4938.2	5115.6	4978.1
4	5083.5	4859.8	4957.3	4911.1
5	5126.3	4974.3	4779.3	4665.6
6	4835.5	4497.8	4961.2	4865.0
7	5262.8	5007.1	4968.7	4925.7
8	4991.7	4801.7	5023.4	4945.6
9	4815.1	4831.6	4834.6	4788.7
10	4943.2	4808.7	4923.0	4694.1

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